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U.S. DEPARTMENT OF COMMERCE; PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
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U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/786321

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP00/04781	14 July 2000	14 July 1999

TITLE OF INVENTION
CONTROLLABLE MAGNETIC BEARING APPARATUS AND METHOD FOR DETERMINING A MACHINE TYPE OF A MAGNETIC BEARING

APPLICANT(S) FOR DO/EO/US - Hirochika Ueyama

OIPE MAR 0 2 2001 PATENT & TRADEMARK OFFICE

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ■ This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.

2. □ This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.

3. ■ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(l).

4. ■ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. ■ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
a. □ is transmitted herewith (required only if not transmitted by the International Bureau)b ■ has been transmitted by the International Bureau (see Form 308) c. □ is not required, as the application was filed in the United States Receiving Office (RO/US).

6. ■ A translation of the International Application into English (35 U.S.C. 371(c)(2))

7. □ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
a. □ are transmitted herewith (required only if not transmitted by the International Bureau)
b. □ have been transmitted by the International Bureau.
c. □ have not been made; however, the time limit for making such amendments has NOT expired.
d. □ have not been made and will not be made.

8. □ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. ■ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. □ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ■ An Information Disclosure Statement under 37 CFR 1.97 and 1.98. (w/ copy of PTO-1449 and each reference cited therein and Int'l Search Rept)

12. ■ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. □ A FIRST preliminary amendment.
□ A SECOND or SUBSEQUENT preliminary amendment.

14. □ A substitute specification.

15. □ A change of power of attorney and/or address letter.

16. ■ Other items or information:

a) PCT Form PCT/IB/308
b) PCT Request (PCT/RO/101) (In Japanese)
c) Copy of cover page of International Application WO 01/06139 (PCT/JP00/04781) with International Search Report (PCT/ISA/210)
d) Notification of Receipt of Record Copy (Form PCT/IB/301)
e) Notification Concerning Submission of Transmittal of Priority Document (PCT/IB/304)

09/786321

U.S. DEPARTMENT OF COMMERCE; PATENT AND TRADEMARK OFFICE 528 Rec'd PCT/PTO 02 MAR 2001

ATTORNEY'S DOCKET NUMBER 33737W006

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)

17. ■ The following fees are submitted:				CALCULATION	PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO . . . . . $860.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) . . . . . $670.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2) . . . . . $760.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . . $970.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $96.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than □ 20 □ 30 months from the earliest claimed priority date (37 CFR 1.495(e)).				$ -	
Claims	Number Filed	Number Extra	Rate		
Total Claims	3 - 20 =	0	x $18.00	$ -	
Independent Claims	3 - 3 =	0	x $80.00	$ -	
Multiple dependent claim(s) (if applicable)			+ $260.00	-	
TOTAL OF ABOVE CALCULATIONS =				$ 860.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$ 0.00	
SUBTOTAL =				$ 860.00	
Processing fee of $130.00 for furnishing the English translation later than □ 20 □ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ -	
TOTAL NATIONAL FEE =				$ 860.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property. +				$ 40.00	
TOTAL FEES ENCLOSED =				$ 900.00	
				Amount to be refunded	$
				charged	$

a. ■ A check in the amount of $ 900.00 to cover the above fees is enclosed.
b. □ Please charge my Deposit Account No. 02-4300 in the amount of $____ to cover the above fees. A duplicate copy of this sheet is enclosed.
c. ■ The Commissioner is hereby authorized to charge any additional fees which may be required with respect to any deficiency in the above noted "Basic National Fee", or credit any overpayment to Deposit Account No. 02-4300 .

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

SMITH, GAMBRELL & RUSSELL, LLP
1850 M Street, NW - Suite 800
Washington, DC 20036

Tel: (202) 659-2811
Fax: (202) 659-1462

SIGNATURE

Robert G. Weilacher - 20,531
NAME REGISTRATION NO.

Date: March 2, 2001

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DESCRIPTION

Controllable magnetic bearing apparatus and method for determining a machine type of a magnetic bearing

TECHNICAL FIELD

The present invention relates to a controllable magnetic bearing apparatus and a method for determining a machine type of a magnetic bearing.

BACKGROUND ART

The controllable magnetic bearing apparatus consists of a machine body including a rolling element and magnetic bearings, and a control unit for controlling the machine body. There are plural types of machine bodies so that control parameters vary depending upon the machine types. Accordingly, there has been a need for providing each control unit in correspondence to each type of machine body.

In order to provide each control unit in correspondence to each type of machine body, multiple types of control units must be fabricated on a small-lot basis. This not only imposes inconvenience but also makes it impossible to reduce costs through mass production.

In view of the foregoing, the present invention has an object to provide a controllable magnetic bearing apparatus having a control unit applicable to multiple types of machine bodies. It is another object of the present invention to provide a method for determining a machine type to apply the control unit to any of the multiple types of machine bodies.

DISCLOSURE OF THE INVENTION

In accordance with the present invention, a controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprises: means for moving the rolling element in a stationary state in a predetermined direction to determine an amount of movement thereof to a movement limit; and means for determining a machine type of the magnetic bearing based on the amount of movement and setting control parameters (Claim 1).

In the controllable magnetic bearing apparatus thus arranged, the amount of movement of the rolling element is determined by moving the rolling element in a stationary state to the movement limit. The machine type is determined based on a fact that the amount of movement varies depending upon the machine types and

then, the setting of control parameters is made. Accordingly, a common control unit can be applied to the multiple types of machine bodies.

In accordance with the present invention, a controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprises: means for moving the rolling element in a stationary state in plural directions to determine respective amounts of movement of the rolling element to respective movement limits; means for determining a mean amount of movement based on the amounts of movement; and means for determining a machine type of the magnetic bearing based on the mean amount of movement and setting control parameters (Claim 2).

In the controllable magnetic bearing apparatus thus arranged, determined is the mean amount of movement of the rolling element when the rolling element in a stationary state is moved to the movement limits in the plural directions. Subsequently, the machine type is determined based on a fact that the mean amount of movement varies with each machine type, so as to set the control parameters. Accordingly, a common control unit can be applied to multiple types of machine bodies. In addition, the determination of the machine type is

highly reliable because the determination is based on the mean amount of movement.

In accordance with the present invention, a method for determining a machine type of a magnetic bearing comprises: the steps of moving a rolling element supported by a magnetic bearing from a rest position to place on one side of a first radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on one side of a second radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on the other side of the first radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on the other side of the second radial axis for determining an amount of movement thereof to a movement limit; operating a mean amount of movement based on the amounts of movement; and determining a machine type of the magnetic bearing based on the mean amount of movement and setting control parameters (Claim 3).

In the method for determining the machine type of the magnetic bearing, the mean amount of movement is found from the amounts of movement of the rolling element, which, initially being in a stationary state, is sequentially moved to each of the movement limits in

each of the different directions. The machine type is determined based on the fact that the mean amount of movement varies with each machine type. Then, the setting of control parameters is made. Accordingly, a common control unit can be applied to multiple types of machine bodies. The determination of the machine types is highly reliable because the determination is based on the mean amount of movement.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a flow chart showing a method of machine type determination taken by a controllable magnetic bearing apparatus according to one embodiment of the present invention;

FIG.2 is a plan view showing the positional relationship between an inside-diameter circle of a protective bearing and a rolling element movable in a range inscribed by the circle;

FIG.3 is a diagram showing the rolling element of FIG.2 internally touching a +Y side of the inside-diameter circle;

FIG.4 is a diagram showing the rolling element of FIG.2 internally touching a +X side of the inside-diameter circle;

FIG.5 is a diagram showing the rolling element of

FIG.2 internally touching a -Y side of the inside-diameter circle;

FIG.6 is a diagram showing the rolling element of FIG.2 internally touching a -X side of the inside-diameter circle;

FIG.7 is a diagram showing each position of the center of and each amount of movement of the rolling element when the rolling element is sequentially moved to each of movement limits thereof;

FIG.8 is a diagram showing each position of the center of and each amount of movement of the rolling element when the rolling element is sequentially moved to each of movement limits thereof, in a case where an initial position of the center of the rolling element is out of the origin of the X-Y coordinates;

FIG.9 is a vertical sectional view showing a machine body of the controllable magnetic bearing apparatus;

FIG.10 is a horizontal sectional view showing the above machine body;

FIG.11 is a block circuit diagram of the above controllable magnetic bearing apparatus;

FIG.12 is a block diagram showing only a portion of the arrangement of the controllable magnetic bearing apparatus that is involved in the control of radial

position; and

FIG.13 is a block diagram showing only a portion of the arrangement of the controllable magnetic bearing apparatus that is involved in the control of axial position.

BEST MODES FOR CARRYING OUT THE INVENTION

FIG.9 is a vertical sectional view showing a machine body 1 of a controllable magnetic bearing apparatus according to one embodiment of the present invention, and FIG.10 is a horizontal sectional view thereof.

The machine body 1 is of a vertical construction wherein a rolling element 3 in the form of a vertical shaft rotates within a cylindrical casing 2. In the following description, an axial direction of the rolling element 3 is defined as Z direction and respective directions orthogonal to the Z direction, as seen in the figure, are defined as X direction and Y direction.

Besides the casing 2 and rolling element 3, the machine body 1 further includes an axial magnetic bearing 4, a radial magnetic bearing 5, an axial displacement sensor 6, a radial displacement sensor 7, a motor 8, and a protective bearing 9.

The axial magnetic bearings 4 are disposed above

and below a flanged portion 3a of the rolling element 3 as sandwiching the flanged portion therebetween, thereby axially supporting the rolling element 3 in a noncontact fashion. The radial magnetic bearings 5 are disposed at two places on Z-axis thus forming two groups, each of which consists of four radial magnetic bearings equally spaced by 90° around the rolling element 3. The radial displacement sensors 7 are disposed at the same circumferential positions as the radial magnetic bearings 5 in close adjacency thereto along the Z direction, thus forming two groups of four. The axial displacement sensor 6 is disposed opposite to an axial end portion 3b of the rolling element 3. The motor 8 is mounted to an inside wall of the casing 2 for rotating the rolling element 3 at high speeds. The protective bearings 9 are arranged in paired relation for limiting movable ranges of the rolling element 3 with respect to the axial and radial directions, as well as for providing contact support for the rolling element 3 in case the magnetic noncontact support for the rolling element 3 may be disabled. A radial clearance and an axial clearance between the protective bearing 9 and the rolling element 3 are of given values determined according to the type of the machine body 1.

FIG.11 is a block circuit diagram showing

connection between the machine body 1 of the above arrangement and a control unit 11 forming, in combination with the machine body, the controllable magnetic bearing apparatus.

The control unit 11 includes a sensor circuit 12, a magnetic-bearing drive circuit 13, an inverter 14, a DSP board 15 and a serial communication board 21. The DSP board 15 is provided with a DSP 16 as a digital signal processor, a ROM 17 connected thereto, a flash memory 18 as a nonvolatile storage device, an A/D converter 19 and a D/A converter 20.

A personal computer 22 disposed at place remote from the control unit 11 is connected to the serial communications board 21 of the control unit 11.

Output signals from the axial displacement sensor 6 and radial displacement sensors 7 are inputted to the DSP 16 via the sensor circuit 12 and A/D converter 19. On the other hand, the DSP 16 provides control of the axial magnetic bearings 4 and radial magnetic bearings 5 via the D/A converter 20 and magnetic-bearing drive circuit 13, thereby allowing the rolling element 3 to be supported in the noncontact fashion as controlling the position of the rolling element 3. The DSP 16 also controls the rotation of the motor 8 via the inverter 14.

The ROM 17 stores a processing program and the like to be performed in the DSP 16. The flash memory 18 stores data which include plural sets of control parameters corresponding to the plural types of machine bodies 1, mean movement spans S (to be described hereinlater in detail) corresponding to the plural types of machine bodies 1, a bias current value Io to be described hereinlater and the like. These data items can be rewritten through the personal computer 22.

FIG.12 is a block diagram showing only a portion of the arrangement of the control unit 11 that is involved in the control of radial position. It is assumed that the pair of radial displacement sensors 7 shown in the figure are, for example, disposed opposite to each other across the rolling element 3 along X-axis. The outputs from these radial displacement sensors 7 are inputted to the sensor circuit 12 in which a processing is performed to subtract one of the outputs from the other. An output from the sensor circuit 12 is A/D converted for giving a displacement signal ΔX. The signal indicates a displacement of the rolling element 3 from a target position with respect to X-axis. The DSP 16 outputs two exciting current signals (Io+Ic) and (Io-Ic) based on the displacement signal ΔX. Io means herein a bias current value, and Ic means a control current

value depending upon the sign and magnitude of ΔX. The exciting current signals (Io+Ic) and (Io-Ic) are each D/A converted and then amplified by an amplifier 13a in the magnetic-bearing drive circuit 13. The amplified signals are supplied to the pair of radial magnetic bearings 5 opposing each other across the rolling element 3 along X-axis. According to the displacement signal ΔX, adjustment is made to the electromagnetic force with respect to a direction in which the displacement is reduced to 0. As a result, the rolling element 3 is supported at the X-axis target position.

A similar positional control is performed on Y-axis.

FIG.13 is a block diagram showing only a portion of the arrangement of the control unit 11 that is involved in the control of axial position. An output from the axial displacement sensor 6 is inputted to the sensor circuit 12. Based on the output signal from the axial displacement sensor 6, the sensor circuit 12 determines a displacement of the rolling element 3 with respect to a Z-axis target position. This displacement is A/D converted to a displacement signal ΔZ which is inputted to the DSP 16. The DSP 16 outputs two exciting current signals (Io+Ic) and (Io-Ic) based on the displacement

signal ΔZ. Io means herein a bias current value, and Ic means a control current value depending upon the sign and magnitude of ΔZ. The exciting current signals (Io+Ic) and (Io-Ic) are each D/A converted and then amplified by the amplifier 13a in the magnetic-bearing drive circuit 13. The amplified signals are supplied to the axial magnetic bearings 4 disposed above and below the flanged portion 3a of the rolling element 3. Based on the displacement signal ΔZ, adjustment is made to the electromagnetic force with respect to a direction in which the displacement is reduced to 0. As a result, the rolling element 3 is supported at the Z-axis target position.

The controllable magnetic bearing apparatus of the above arrangement constitutes means for performing the rotation control and the positional control of the rolling element 3. Furthermore, the controllable magnetic bearing apparatus also constitutes: means which, at the start of operation, uses a positional control function centralized on the DSP 16 to move the rolling element 3 in a stationary state in a predetermined direction for determining an amount of movement thereof to a movement limit; and means which determines the machine type of magnetic bearing (machine body 1) based on the determined amount of movement for

setting control parameters. An operation for determining the machine type will hereinbelow be described in detail.

In the above controllable magnetic bearing apparatus, the axial magnetic bearing 4, radial magnetic bearing 5 and motor 8 are not driven when the control unit 11 is not powered up. Therefore, the rolling element 3 is at rest as supported by the protective bearings 9 in contact fashion. Upon power-up of the control unit 11, the DSP 16 identifies the machine body 1 according to a flow chart of FIG.1. The embodiment assumes that there are three types of machine bodies 1 which include Type-A, Type-B and Type-C. The length of the clearance between the rolling element 3 and the protective bearing 9 varies with each machine type.

First in Step S1, the DSP 16 takes measurement of the amount of movement to the movement limit. Specifically, the DSP reads provisional control parameters from the flash memory 18 to drive the axial magnetic bearings 4. This allows the rolling element 3 to be magnetically levitated to a provisional target position on Z-axis. In this state, the rolling element 3 is allowed to move in the radial direction within the range defined by the inside-diameter circle of the protective bearing 9.

FIG.2 to FIG.6 are diagrams illustrating in plan the positional relationship between an inside-diameter circle C of the protective bearing 9 and the rolling element 3 movable within an inscribed range of the circle. First assume as an initial state that the rolling element 3 is positioned concentrically with the inside-diameter circle C, as shown in FIG.2. In this state, the DSP 16 stores a displacement signal ΔY0(=0) based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. Subsequently, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the +Y direction to thereby attract the rolling element 3 in the +Y direction. This brings the rolling element 3 into internal contact with the +Y side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.3). In this state, the DSP 16 reads a displacement signal ΔY1 based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. The DSP 16 calculates a difference (ΔY1-ΔY0) between the displacement signal ΔY1 and the previously stored displacement signal ΔY0. Additionally, the DSP 16 determines an amount YLp (of positive sign) of movement of the rolling element 3 moved in the +Y direction from the position of FIG.2 to that of FIG.3 using a previously inputted corresponding

relationship between the displacement signal and the actual displacement, and then stores the amount of movement thus determined. Furthermore, the DSP 16 stores a displacement signal $\Delta X0(=0)$ based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the +X direction to thereby attract the rolling element 3 in the +X direction. This brings the rolling element 3 into internal contact with the +X side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.4). In this state, the DSP 16 reads a displacement signal $\Delta X1$ based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions. The DSP 16 calculates a difference $(\Delta X1-\Delta X0)$ between the displacement signal $\Delta X1$ and the previously stored displacement signal $\Delta X0$. Based on the calculation result, the DSP 16 determines an amount XLp (of positive sign) of movement of the rolling element 3 moved in the +X direction from the position of FIG.3 to that of FIG.4, then storing the amount of movement thus determined.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the -Y direction to thereby attract the rolling element 3

in the -Y direction. This brings the rolling element 3 into internal contact with the -Y side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.5). In this state, the DSP 16 reads a displacement signal $\Delta Y2$ based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. The DSP 16 calculates a difference ($\Delta Y2-\Delta Y0$) between the displacement signal $\Delta Y2$ and the previously stored displacement signal $\Delta Y0$. Based on the calculation result, the DSP 16 determines an amount YLn (of negative sign) of movement of the rolling element 3 moved in the -Y direction from the position of FIG.2 to that of FIG.5, then storing the amount of movement thus determined.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the -X direction to thereby attract the rolling element 3 in the -X direction. This brings the rolling element 3 into internal contact with the -X side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.6). In this state, the DSP 16 reads a displacement signal $\Delta X2$ based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions. The DSP 16 calculates a difference ($\Delta X2-\Delta X0$) between the displacement signal $\Delta X2$ and the previously stored displacement signal $\Delta X0$. Based on the calculation

result, the DSP 16 determines an amount XLn (of negative sign) of movement of the rolling element 3 moved in the -X direction from the position of FIG.3 to that of FIG.6, then storing the amount of movement thus determined.

FIG.7 is a plot of positions P0, P1, P2, P3 and P4 of the center of the rolling element 3 moved from the state of FIG.2 in the aforementioned manner or in the order of FIG.3, FIG.4, FIG.5 and FIG.6 as maintained in internal contact with the protective bearing 9. It is noted that the aforementioned amounts of movement YLp, XLp, YLn, and XLn are such lengths as shown in FIG.7.

It is noted that the initial position P0 of the center of the rolling element 3 is not always at the center of P1 to P4, as shown in FIG.8. In this case, YLp and YLn are not equal to each other because they are read with reference to the displacement signal ΔY0 with respect to P0. Even in this case, however, the center of the rolling element 3 is moved to the position of P1 when the rolling element 3 is attracted by the radial magnetic bearing 5 in the +Y direction. Accordingly, the amounts of movement, XLp and XLn are the same as in the case shown in FIG.7.

Based on the amounts of movement, YLp, XLp, YLn and XLn thus determined, the DSP 16 calculates a mean

value of movement span S (Step S2). Specifically, movement spans Ys and Xs in the Y and X directions are first determined using:

$$Ys=YLp-YLn$$

$$Xs=XLp-XLn$$

Next, the mean value of movement span S is determined using:

$$S=(Ys+Xs)/2\ldots(1)$$

The reliability of the determination of the machine type (described later) is enhanced by determining the mean value S with respect to both the X and Y directions.

Subsequently, the DSP 16 determines whether or not the mean value of movement span S satisfies:

$$S1min \leqq S \leqq S1max\ldots(2)$$

where S1min and S1max denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-A (Step S3). If the machine body 1 is Type-A, the answer to the above expression (2) is YES. Therefore, the DSP 16 proceeds to Step S7 to read in control parameters for Type-A from the flash memory 18 and to set, based on the read control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

If the machine body 1 is not Type-A, then the answer

to the above expression (2) is NO. Therefore, the DSP 16 proceeds to Step S4 to determine whether or not the mean value of the movement span S satisfies:

$$S2min \leqq S \leqq S2max \ldots (3)$$

where S2min and S2max denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-B (provided that S1max < S2min). If the machine body 1 is Type-B, the answer to the above expression (3) is YES. Therefore, the DSP 16 proceeds to Step S8 to read in control parameters for Type-B from the flash memory 18 and to set, based on the control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

If the machine body 1 is not Type-B, the answer to the above expression (3) is NO. Therefore, the DSP 16 proceeds to Step S5 to determine whether or not the mean value of the movement span S satisfies:

$$S3min \leqq S \leqq S3max \ldots (4)$$

where S3min and S3max denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-C (provided that S2max < S3min). If the machine body 1 is Type-C, the answer to the above expression (4) is YES. Therefore, the DSP 16 proceeds to Step S9

to read in control parameters for Type-C from the flash memory 18 and to set, based on the control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

If the machine body 1 is not Type-C, the answer to the above expression (4) is NO. Accordingly, the machine body 1 is not any of Type-A, Type-B and Type-C, so that the determination of machine type cannot be made. Therefore, the DSP 16 proceeds to Step S6 to indicate abnormality.

In this manner, the type of machine body 1 can be determined from the mean value of the movement spans S, and thereby the setting of control parameters for an applicable machine type is automatically made for quickly transferring the rolling element to a magnetically levitated state. Thus, the common control unit 11 makes it possible to automatically set appropriate control parameters for any of the plural types of machine bodies 1 and to control the position of the rolling element 3. This permits the control unit 11 to be applied to general purposes, so that the control unit 11 can be mass-produced for achieving the cost reduction. It is noted that abnormality is indicated only when the automatic determination is impossible and then an operator sets the control parameters based on

his determination.

Although the flow chart (FIG.1) of the foregoing embodiment illustrates the processing for selecting any one of the three types, it is also possible to make determination as to the larger number of machine types for automatic setting of the control parameters.

Although the foregoing embodiment determines the machine type based on the amounts of movement YLp, XLp, YLn and XLn, it is also possible to determine the machine type based on only the amount of movement in the Y direction or X direction.

In the foregoing embodiment, prior to the determination of the amounts of movement YLp, XLp, YLn and XLn, the axial magnetic bearings 4 are excited to effect a provisional state where the rolling element is levitated in the axial direction. However, the rolling element 3 may not be axially levitated if the rolling element 3 can be axially attracted even in a state where the rolling element is in contact with the protective bearings 9.

In the foregoing embodiment, the determination of the machine type is made based on the amount of movement to the movement limit in the radial direction. However, it is also possible to determine the machine type based on the amount of movement to the movement limit in the

axial direction. In this case, the rolling element 3 in a stationary state is levitated to bring its axial end portion 3a into abutment against the protective bearing 9 so that an amount of movement may be determined from an amount of variation of the displacement signal ΔZ from the axial displacement sensor 6 and then the machine type is determined based on this amount of movement.

CLAIMS

1. A controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprising:

means for moving said rolling element in a stationary state in a predetermined direction to determine an amount of movement thereof to a movement limit; and

means for determining a machine type of the magnetic bearing based on said amount of movement and setting control parameters.

2. A controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprising:

means for moving said rolling element in a stationary state in plural directions to determine respective amounts of movement thereof to respective movement limits;

means for determining a mean amount of movement based on said amounts of movement; and

means for determining a machine type of the magnetic bearing based on the mean amount of movement and setting control parameters.

3. A method for determining a machine type of a magnetic bearing comprising the steps of:

moving a rolling element supported by a magnetic bearing from a rest position to place on one side of a first radial axis and determining an amount of movement thereof to a movement limit;

then moving said rolling element to place on one side of a second radial axis and determining an amount of movement thereof to a movement limit;

then moving said rolling element to place on the other side of the first radial axis and determining an amount of movement thereof to a movement limit;

then moving said rolling element to place on the other side of the second radial axis and determining an amount of movement thereof to a movement limit;

operating a mean amount of movement based on said amounts of movement; and

determining a machine type of the magnetic bearing based on said mean amount of movement and setting control parameters.

ABSTRACT

A rolling element in a stationary state as surrounded by magnetic bearings is moved until it abuts against a protective bearing, and thereby a mean value of movement spans S is determined. A machine type is determined based on a fact that the mean value of movement spans varies depending upon the types of machine bodies, and then the setting of control parameters is made. In this manner, a control unit of the magnetic bearing is adapted for multiple types of machine bodies.

FIG. 1

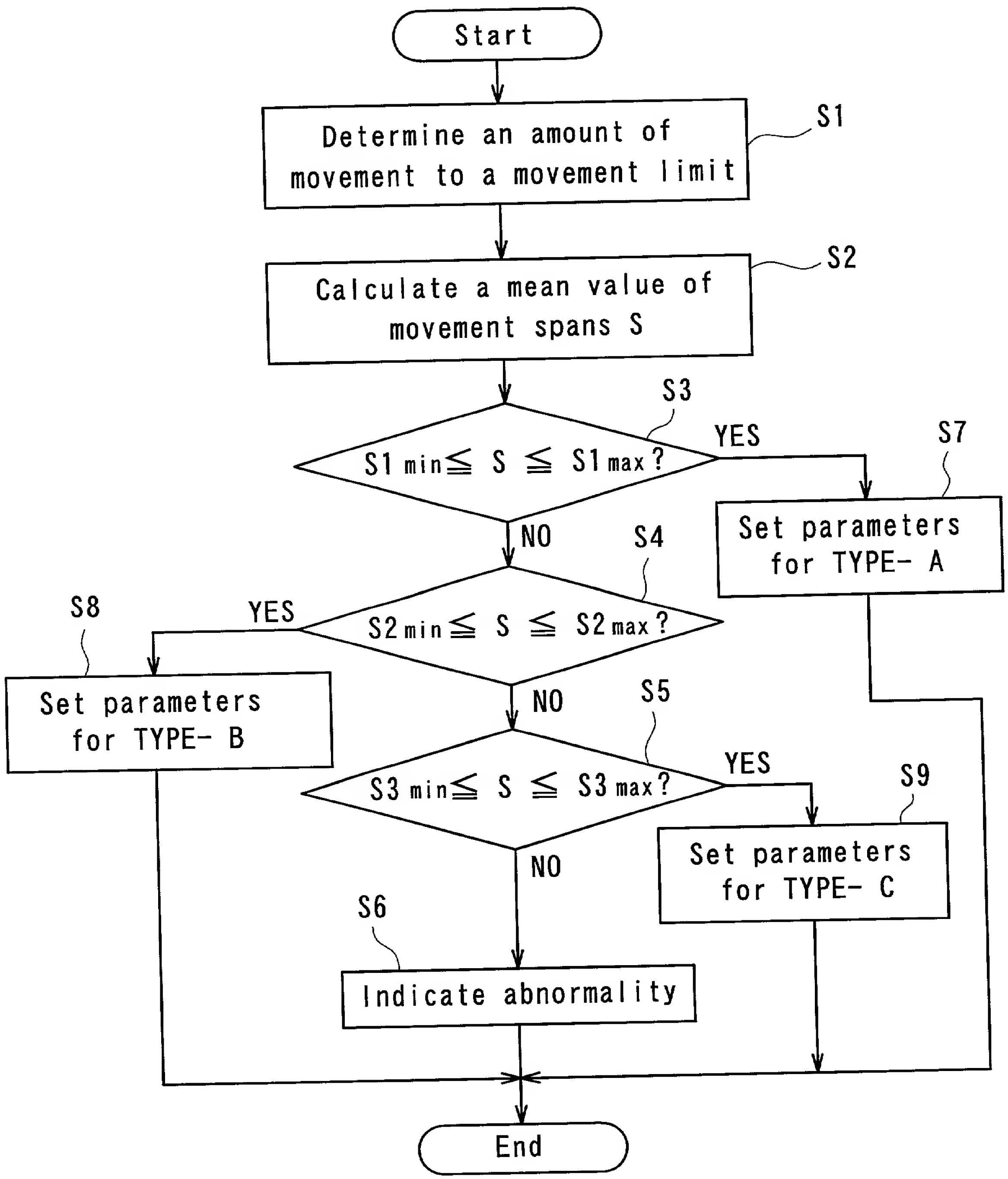
Start
Determine an amount of movement to a movement limit
S1
Calculate a mean value of movement spans S
S2
S3
S1 min≦ S ≦ S1 max ?
YES
S7
Set parameters for TYPE- A
NO
S4
S8
YES
S2 min≦ S ≦ S2 max ?
Set parameters for TYPE- B
NO
S5
S3 min≦ S ≦ S3 max ?
YES
S9
Set parameters for TYPE- C
NO
S6
Indicate abnormality
End

FIG. 2

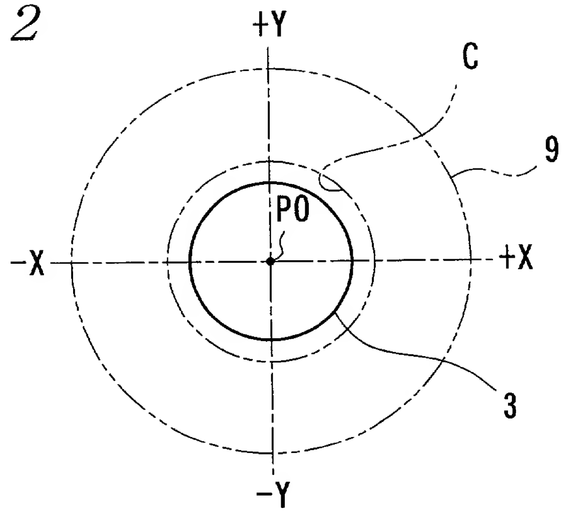

FIG. 3

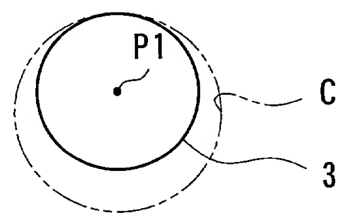

FIG. 4

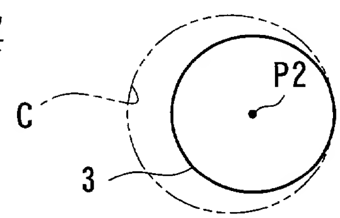

FIG. 5

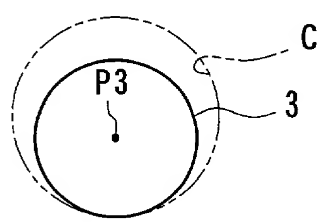

FIG. 6

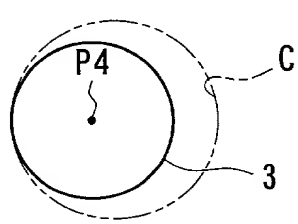

FIG. 7

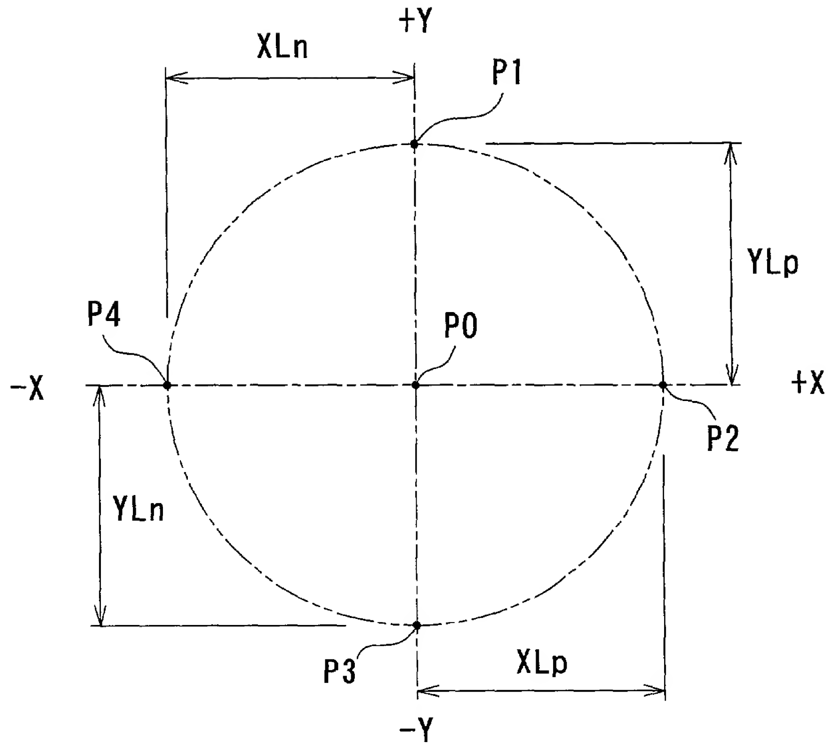
+Y
XLn
P1
YLp
P4
P0
-X
+X
P2
YLn
P3
XLp
-Y

FIG. 8

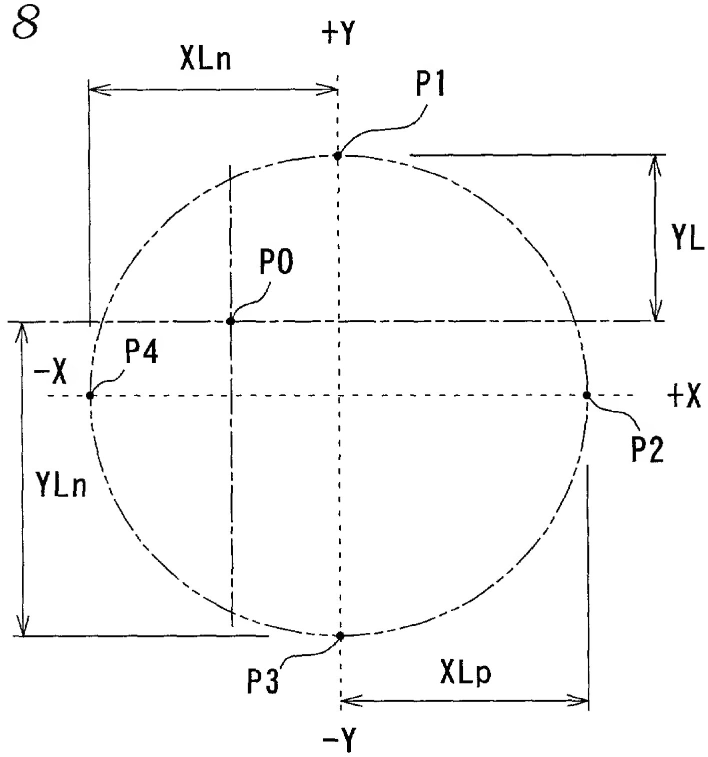
+Y
XLn
P1
YLp
P0
-X
P4
+X
P2
YLn
P3
XLp
-Y

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FIG. 9

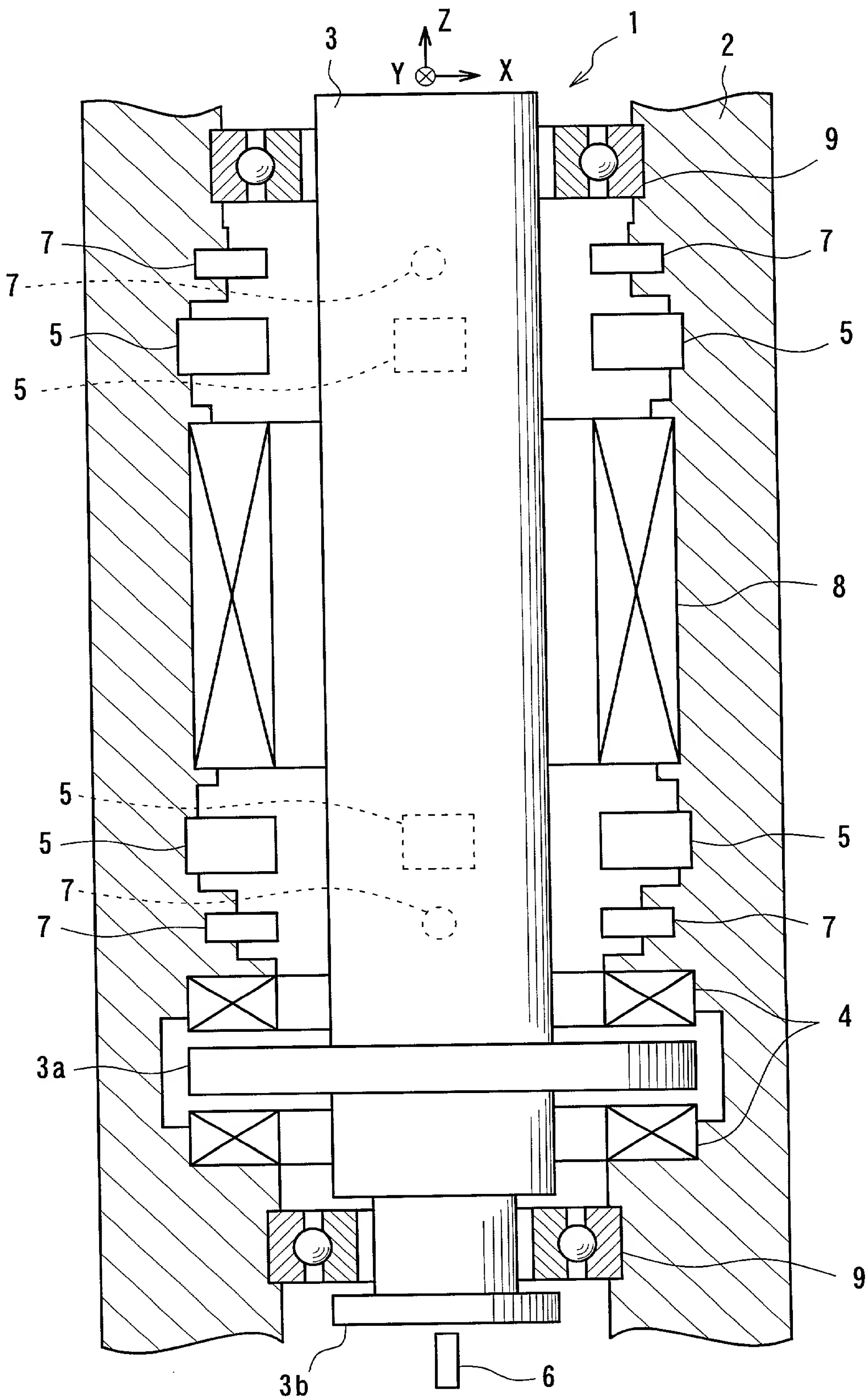

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FIG. 10

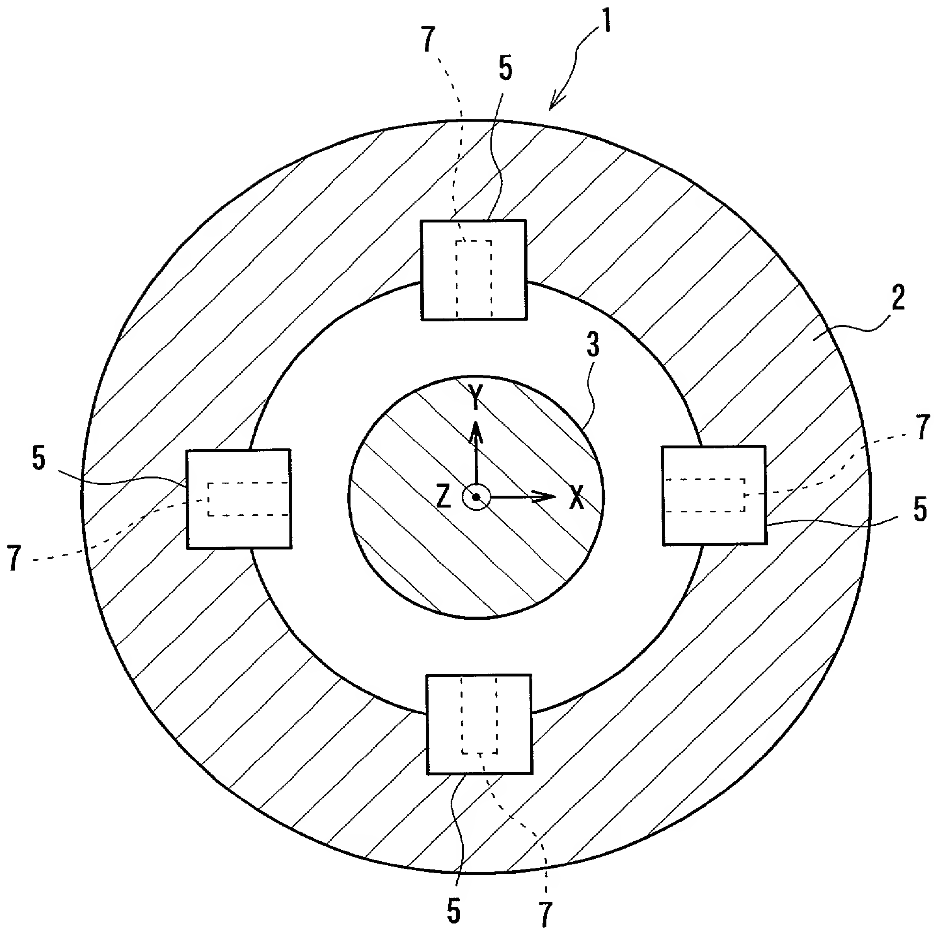
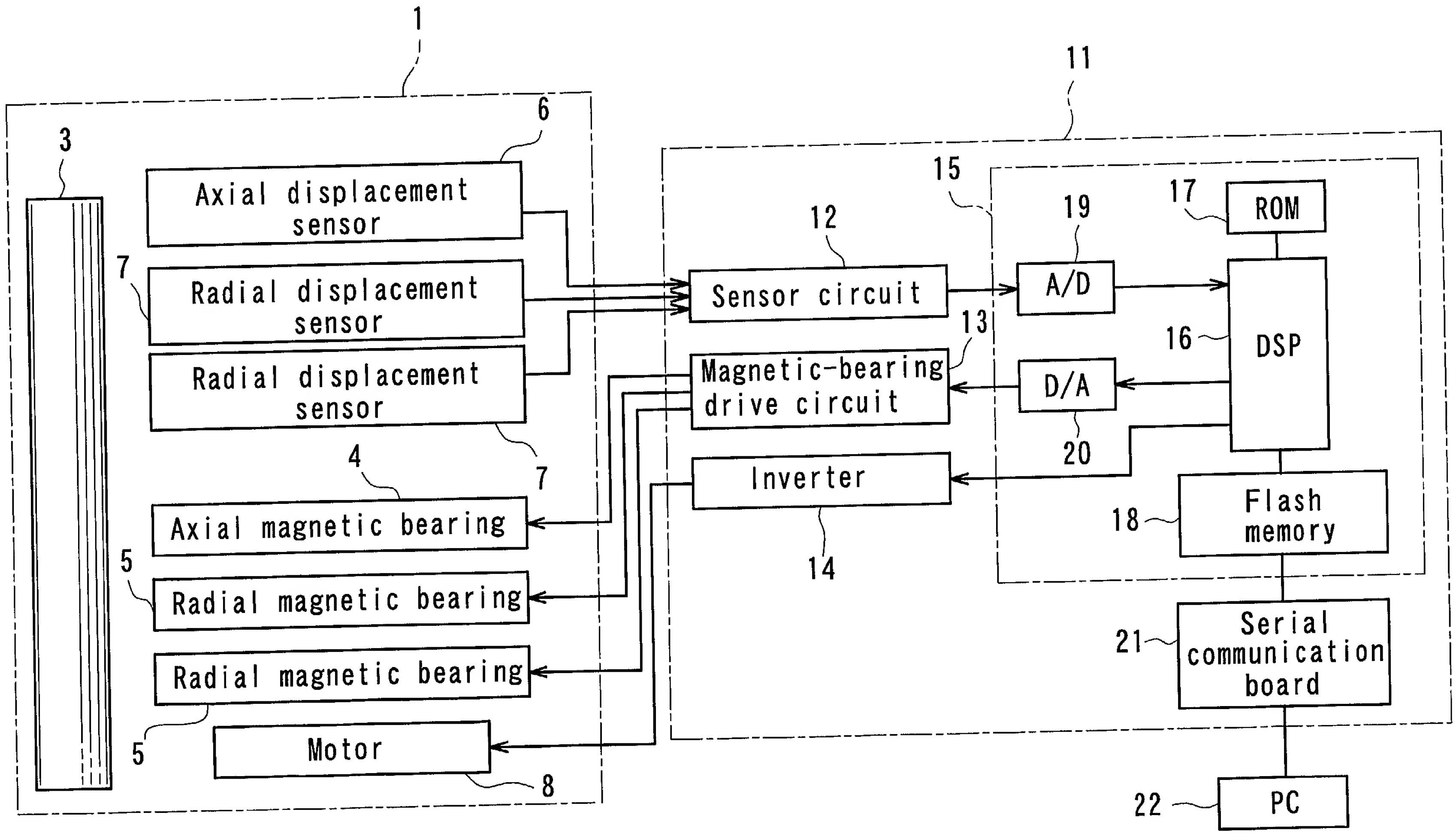


FIG. 1 1


1
3
6
Axial displacement sensor
7
Radial displacement sensor
Radial displacement sensor
7
4
Axial magnetic bearing
5
Radial magnetic bearing
Radial magnetic bearing
5
Motor
8
11
15
12
Sensor circuit
13
Magnetic-bearing drive circuit
Inverter
14
19
A/D
17
ROM
16
DSP
D/A
20
18
Flash memory
21
Serial communication board
22
PC

09/786321

FIG. 12

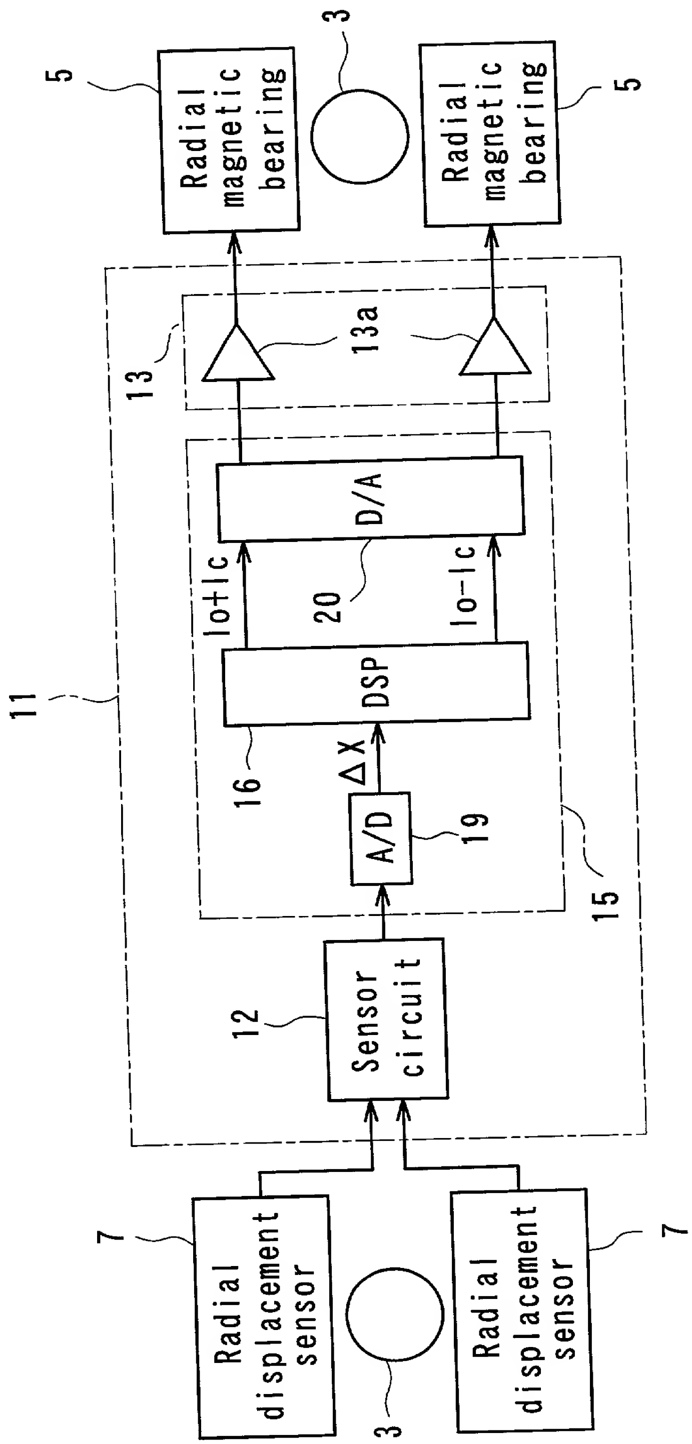
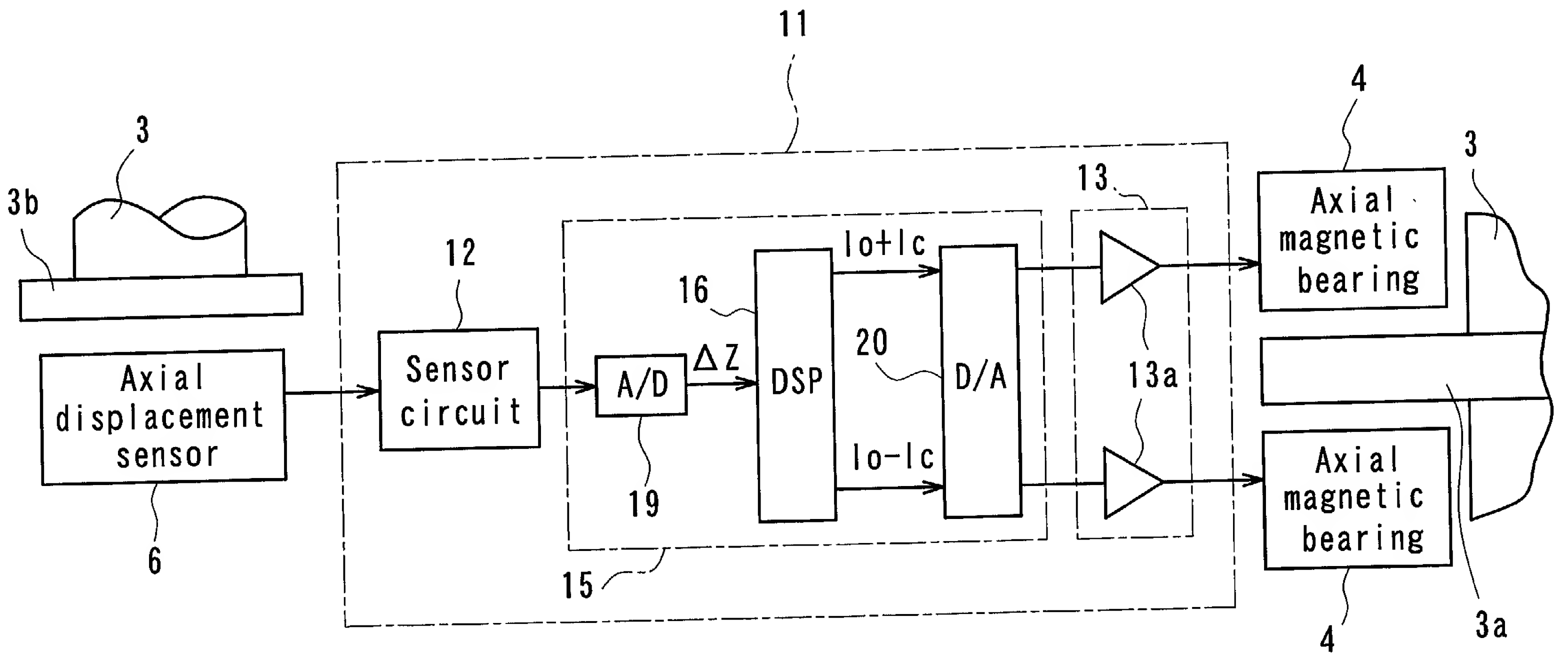


FIG. 13



11
3
3b
Axial displacement sensor
6
12
Sensor circuit
A/D
19
ΔZ
16
DSP
15
Io+Ic
Io−Ic
20
D/A
13
13a
4
Axial magnetic bearing
Axial magnetic bearing
4
3
3a

UNITED STATES
Patents and Design Patents
Sole & Joint Inventors
Convention & Non-convention
PCT & Non-PCT
This form cannot be amended, altered or changed after it is signed.
(For use only for inventors who understand the English language.)

Declaration and Power of Attorney
United States Patent Application

As a below named inventor, I hereby declare that:
My residence, post office address and citizenship are as stated below next to my name.
I believe I am the original, first and sole inventor *(if only one name is listed below)* or an original, first and joint inventor *(if plural names are listed below)* of the subject matter which is claimed and for which a patent is sought on the invention entitled CONTROLLABLE MAGNETIC BEARING APPARATUS AND METHOD FOR DETERMINING A MACHINE TYPE OF A MAGNETIC BEARING

(check one) ☐ is attached hereto.
☐ was filed as U.S. Application No.________ on ________ and *(if applicable)* was amended on ________.
■ was filed as PCT International Application No. PCT/JP00/04781 on July 14, 2000 and *(if applicable)* was amended under PCT Article 19 on ________.

I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) or §365(b) of any foreign and PCT application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designated at least one country other than the United States of America listed in this Declaration. I have also identified below any foreign application for patent or inventor's certificate or PCT international application having a filing date before that of the application(s) on which priority is claimed:

Foreign/PCT Application No.	Country	Filing Date	Priority Claimed? (yes/no)
11/200475	Japan	July 14, 1999	Yes

I hereby claim the benefit under Title 35, United States Code, §120 or §365(c) of any United States application and PCT international application designating the United States of America listed in this Declaration and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

U.S. Application No.	Filing Date	*Status (patented/pending/abandoned?)*

I hereby claim priority benefits under Title 35 United States Code §119(e) of any U.S. provisional application(s) listed below:

U.S. Provisional Application No.	Filing Date

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: Robert G. Weilacher (20,531), Herbert M. Hanegan (25,682), Dale Lischer (28,438), Frederick F. Calvetti (28,557), J. Rodgers Lunsford, III (29,405), Michael A. Makuch (32,263), Dennis C. Rodgers (32,936), William F. Rauchholz (34,701), Michael C. Carrier (42,391), Eric J. Hanson (44,738), Patrick R. Delaney (45,338), Joseph M. Lewinski (46,383) and Brandon S. Boss (46,567).

Send all correspondence to: Smith, Gambrell & Russell, LLP, Beveridge, DeGrandi, Weilacher & Young Intellectual Property Group, 1850 M Street, N.W. (Suite 800), Washington, D.C. 20036. All facsimiles may be sent to (202) 263-4329. Direct all phone calls to (202) 659-2811.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

1-00

Full name of sole or first inventor: Hirochika Ueyama
Citizenship: Japan
Residence *(city, state, country)*: Hirakata-shi, Osaka, Japan JPX
Post office address: 9-38, Uyama-cho, Hirakata-shi, Osaka 573-1143, Japan

Signature: Hirochika Ueyama
Date: FEB. 20. 2001